VENUS STRATOSPHERIC SOUNDER: FIRST *IN SITU* MEASUREMENTS IN UPPER CLOUD REGION

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ABSTRACT

In spite of intensive ground-based and space observations, many major questions about the Venus are still unanswered. Among them are the nature, pattern and evolution of the atmospheric circulation in the troposphere and stratosphere, the nature and distribution of the UV-absorber, and the structure and composition of the stratospheric clouds. There is no accurate data on the vertical structure of the lowest 12 km. The stratosphere, with exception of the probes' accelerometer data, has been essentially unexplored with *in situ* measurements. It is also unknown if any noticeable changes in the structure and circulation of the atmosphere have occurred since the last Vega mission in 1985.

Future missions, such as the Venus Surface Sample Return Mission, require improved knowledge of the Venus atmospheric environment where these missions need to operate with much better accuracy and less risk than before. The proposed Venus Statospheric Sounder Mission could serve as a low-cost effective precursor to this more ambitious project.

The main element of the mission is the balloon-borne sonde that will ascend to 80-82 km altitude after aerial deployment and inflation at 55-60 km and will transmit data direct to Earth on the way through the atmosphere. The basic set of instruments may include pressure and temperature sensors, nephelometer, and sensors to measure the chemical composition of clouds. DVLBI tracking of the balloon will give an accurate wind profile of the atmosphere of Venus. It will be the first mission that will provide data on the Venus stratosphere with high vertical resolution. The mission is lightweight and can be delivered on the Micromission Probe Vehicle.

INTRODUCTION

In the last years the interest in Venus exploration was overshadowed with spectacular discoveries in the outer planets and an intensive Mars exploration program.

At the same time Venus, being the closest planet to Earth and similar in some respects (mass, size, gravity, dense atmosphere), differs dramatically in others – the most pronounced are high surface temperatures and pressures, super-rotation of the atmosphere, absence of water and sulfuric acid clouds. With the global warming problem, Venus could serve as an example of ultimate evolution of Earth-like planet and its detailed study could give insight in the processes controlling the atmosphere of our planet.

In the sixties, two sets of Earth-based observations stimulated initial interest in Venus: anomalous high radiation in RF frequencies and fast rotation of the upper atmosphere cloud systems visible in UV only.

19 vehicles studied *in situ* Venus atmosphere: 11 Venera probes (Veneras 4-14), two VEGA landers, two VEGA balloons and four Pioneer Venus probes. 12 orbiters/fly-by gathered remote data: three Mariners (Mariner 2, 5,10), Pioneer Venus orbiter, Magellan, Galileo, four Venera orbiters (Venera 9,10,15,16), and two VEGA. These data reveal many features of the atmosphere.

However a number of fundamental problems is still unresolved and needs further study. Future mission planning – such as the Venus Surface Sample Return mission (VESAR) - one of the prime candidates in the NASA Strategic Plan – requires more accurate and updated knowledge of the Venus atmosphere. To be implemented, the VESAR requires that Venus Ascent Vehicle (VAV) with the sample canister was lifted by balloon to 60-65 km. From this region, VAV could be launched for orbital rendezvous with moderate atmospheric drag loss. Accurate knowledge of the environment near the surface and during ascent could be critical for the success of this mission.

VENUS ATMOSPHERE ENVIRONMENT

The vertical structure of the atmosphere of Venus, as measured by entry probes and orbiters [1], is shown in Fig.1. The middle atmosphere – from 12 to 55 km is covered with the most accurate data. The detailed structure of the lower atmosphere (0 to 12 km) is still unknown; Venera and Vega-2 pressure sensors were not accurate enough, and sensors of Pioneer Venus probes ceased to function below 12 km.

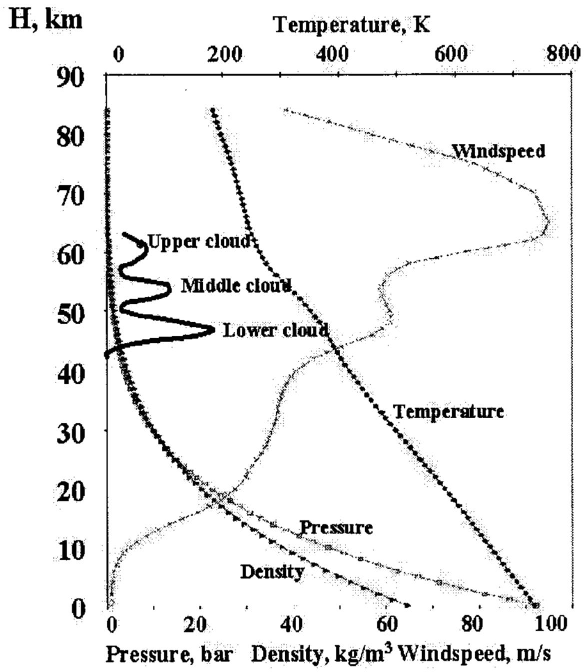

Fig.1. Vertical structure of atmosphere of Venus

There is significant lack of high-resolution data on the atmospheric structure above 55-58 km since the descent probes passed rapidly through this region. Most of data was obtained from remote measurements (radio-occultation, IR-radiometers and IR-spectrometers) and from accelerometers on descent probes.

One of the most enigmatic features of Venus is the atmospheric circulation. Prompted by Earth-based UV observations of high-altitude clouds structure and unambiguously discovered by Venera 8 measurements, the super-rotation phenomena is still remains unexplained. Vertical structure of winds above 55 to 58 km is poorly known since above-mentioned lack of resolution of probes data. Altitude of winds derived from UV-clouds motions is also unknown.

Clouds cover the entire surface of Venus, extending tens kilometers – above approximate base 47-48 km [2]. Of three major cloud layers – low, middle and upper – the latter was less covered with direct measurements. There are still uncertainties in cloud composition and in the nature of the absorber responsible for the appearance of Venus in ultra-violet.

No direct measurements were conducted in polar areas, where a very different thermal pattern was observed by Pioneer Venus IR-radiometer.

MISSION CONCEPT

To directly study the structure of the Venus stratosphere we propose to use a slowly **ascending zero-pressure stratospheric balloon** as the instrument platform. A common earth-based radiosonde is the closest analog (Russian-French-US VEGA balloons [3] flew at constant level 53-54 km).

Baseline concept

The entry vehicle will be delivered to Venus by a micro-spacecraft (Ariane 5 Auxiliary Payload with launch from GTO is a feasible option). One-two months prior to arrival the entry vehicle will be targeted to desired location at the night side of Venus and the spacecraft will perform avoidance maneuver to fly-by the planet. The fly-by will be used to provide a reference source of Differential Very Long Base Interferometry (DVLBI) measurements for velocity of the balloon [4] (Fig.2).

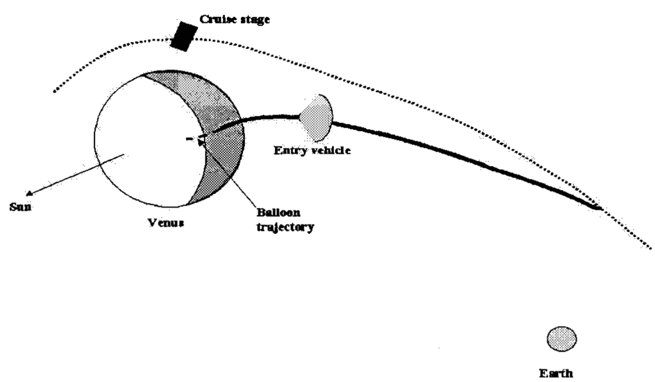

Fig.2. Mission scheme

The entry vehicle will house the lightweight zero-pressure balloon with deployment and inflation system, and the instrumented gondola.

The entry, deployment and inflation (EDI) sequence is shown in Fig.3. After entry and deceleration by aeroshell at an altitude of 58 to 56 km, the back shell will be ejected and the

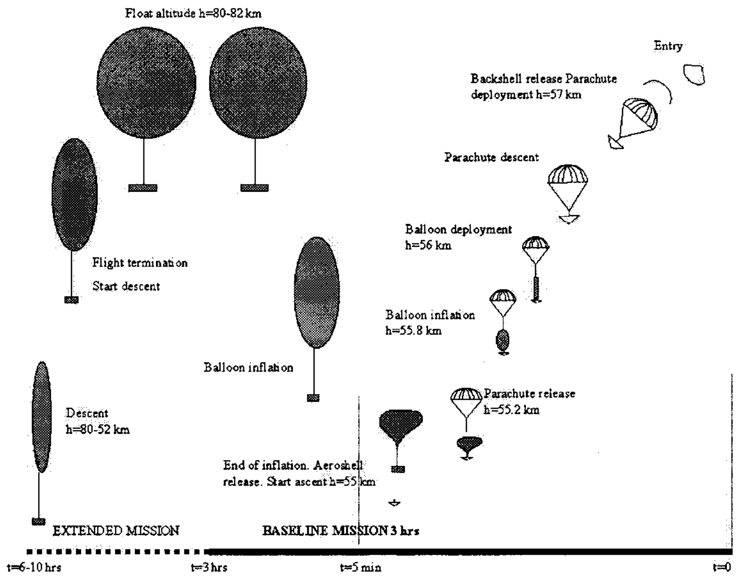

Fig.3. Entry, deployment, inflation sequence. Baseline and extended mission

parachute will be deployed. When the parachute reaches terminal velocity, the balloon container opens and the balloon deploys with the inflation system suspended to the bottom fitting. The inflation process begins, lasting 30 to 60 s. Just prior to completing inflation (about 10 seconds) the parachute separates from the balloon (with inflation system, gondola and aeroshell). In 5-10 s after completion of inflation, the adequate distance between the parachute and the balloon will be achieved and the inflation system will be dropped. The balloon then starts to ascend, with the gondola deployed below the bottom fitting. With an expected rate of ascent of 3 to 5 m/s the balloon will reach its ceiling of 80 to 82 km in 1.5-3 hours.

Data will be transmitted directly to the DSN via one-way X-band link and low-gain antenna. The antenna pattern can be matched to the expected geometry and can take advantage of an almost ideal vertical orientation of the flight system during ascent.

Upgraded concepts

1.Extended mission. Ceiling altitude is controlled by the balloon volume and mass of the system. As in a regular zero-pressure balloon the excess of buoyant gas will be vented at approach to the ceiling. The balloon will float and drift with the wind to the day-side of Venus. Activation of a simple hot-wire device will terminate the flight, and the balloon (and payload) will provide a second-site vertical profile as it descends to the surface.

2.Vertical profile from the surface to 80 to 82 km. A small descent probe similar to the VEVA small sonde [5] could be installed in the aeroshell and released during the EDI sequence. The probe can measure atmospheric parameters down to the surface; in combination with the balloon data it will give first direct measured vertical profile from the surface to 80 to 82 km.

3.Multiple probes: Multiple entry vehicles delivered by a single or multiple cruise carriers will measure atmospheric profiles in multiple locations.

4.Polar sounding: One of the probes could be targeted to the polar region where a distinctively different atmospheric pattern was found by Pioneer Venus IR radiometer [6]. Atmospheric attenuation does not affect X-band signal and data transmission at altitudes above 55 to 60 km providing an opportunity to obtain the first in situ data in this critical polar region.

BALLOON SYSTEM

The balloon has a traditional zero-pressure natural shape design with modifications for aerial deployment and inflation. Due to the relatively benign temperatures (20 to 30-C) at altitude of deployment , the balloon can made of polyethylene. Resistance to sulfuric acid breakdown and low mass density makes Polyethylene a preferrable choice for the Venus cloud environment. Fig.4 shows balloon diameter and mass for 6.25 μ polyethylene balloon as function of payload

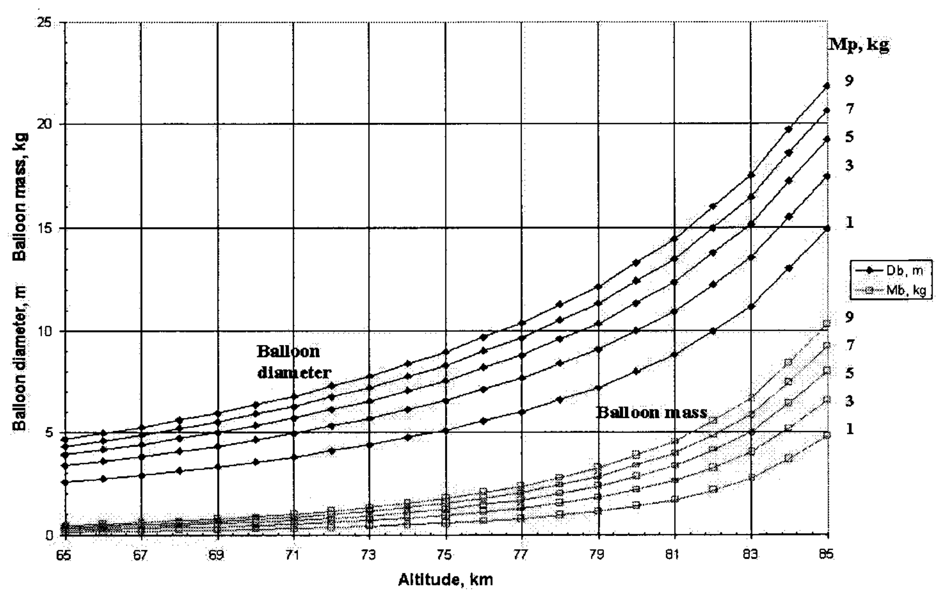

Fig.4. Balloon diameter and mass as functions of ceiling altitude and mass of payload

mass and ceiling altitude.Balloon size and mass grow rapidly when float altitude exceeds 80-82 km. This is likely a limit that can be reached for the payload ~ 5 kg within the the micromission constraints.

To sustain loads during aerial deployment, some of the balloon seams could be reinforced with Spectra fibers. The ripstitch shock absorbers are key elements of the deployment system, effectively limit deployment loads. Other elements of the deployment system are pyro cable-cutters, the balloon container and a system of tethers that connect all parts.

The balloon inflation system consists of a high pressure tank filled with helium or hydrogen, two pyrovalves, inflation hose, diffuser and service valves. The first pyrovalve provide a lower inflation rate at the beginning of the process, the second valve opens 10 to 20 seconds later and provides a high flow rate for rapid inflation. This mid-inflation flow adjustment insures a safe flow rate during initial injection of the gas, and increases flow accordingly during the latter, more benign stages of inflation.

The aerial deployment and inflation of is a critical technology for planetary balloons. It was first demonstrated with VEGA balloons in 1985. The VEGA balloons were relatively small (3.5 m diameter), were made of heavy robust cloth (~300 g/m2), used a top inflation system and were durable enough to survive deployment loads. This cloth is too heavy to be used at the higher altitude balloons.

Successful aerial deployment and inflation of thin-film balloon with bottom inflation system in the Venus-like environment was demonstrated by JPL over El Mirage Dry Lake (California) in August 1998 [7]. A 3-m diameter spherical balloon made of 12-μ Mylar film was dropped from a helicopter, deployed and inflated during descent under the parachute (Fig.5). Several other deployment tests of larger 10-m diameter Mylar balloons were also performed successfully. The

Fig.5. Aerial deployment and inflation of 3-m Mylar balloon.
El Mirage Dry Lake, California, August 21, 1998

deployment process is well understood now. The technology is ready for implementation in the space mission.

INSTRUMENTS

The basic instruments may include pressure and temperature sensors (for measurements of thermal structure) and nephelometer (to study the vertical structure of clouds). No special requirements are imposed on the sensors (especially on the night-side) since the balloon ascends relatively slow. The temperature sensor should be protected from possible deposition of sulfuric acid. Other instruments may include radiometer to measure thermal fluxes and one-axis accelerometer to record the turbulence.

Attempt to measure composition and especially the nature of the UV-absorber seems the most challenging and it is unclear if it is feasible for such a mission.

COMMUNICATIONS AND WIND MEASUREMENTS

The mission will use an X-band transmitter with 5 W RF power output. With an omni-directional antenna (gain~0dB), the system can achieve data rates of 10 to 20-bits/sec at distances of 100 to 150 million kilometers (which are typical for Venus missions). This data rate closely matches the low ascent rate of the balloon, with balloon ascent velocity approximately 5-m/s and the sampling period of approximately 5-sec. The measurements will be taken every 25 meters, providing almost continuos coverage.

The slow-ascending balloon is a good tracer of wind since the horizontal velocity of balloon is equal to local wind velocity. Differential Very Long Base Interferometry (DVLBI) tracking is the most accurate and adequate method to measure drift of the balloon and correspondingly vertical profile of wind. DVLBI effectively measures angular motion of the balloon relative to a reference source which position is known. This method was used successfully to determine winds with Pioneer Venus probes and VEGA balloons. With the cruise stage at fly-by trajectory as the reference source, the expected accuracy of wind measurements will be less than 0.3 m/s.

Lithium batteries will be the primary power source for this short-duration mission. Continuous transmission with a total DC power consumption of 20-W over three hours would require a 200 to 300-g battery. Power management and increase of battery mass would be necessary for upgraded scenarios, which need extended mission lifetime.

Estimated mass of the payload is 3 to 5-kg (payload mass of VEGA balloon was 7 kg for lifetime 46 hours). The whole system could be fit into ASAP micromission constraints.

SUMMARY

The proposed concept of the Venus stratospheric sounder is a low-cost mission with high scientific return providing highly accurate measurements of the Venus stratosphere. The measurements will serve also as a "*in situ* truth" for previous remote measurements and simulations. The approach uses existing technologies that guarantee timely implementation within budget.

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